A program of

Watershed-Management Research

on forest lands in the upper Delaware and Susquehanna River basins

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by

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Introduction

THIS IS A PROPOSED 5-point, 5-year program for watershed-management research at the Kingston Research Center. This Center's area embraces 5 counties in southern New York and 18 counties in northeastern Pennsylvania, an aggregate of 10,247,000 acres or about 16,000 square miles. Its long axis (northeast to southwest) is about 250 miles long, and its breadth measures about 150 miles. It includes about 2 million people and its water resource supplies several million more in adjacent metropolitan areas.

As one of the eight research centers of the Northeastern Forest Experiment Station, the Kingston Center occupies a central position (fig. 1). Its boundaries delineate

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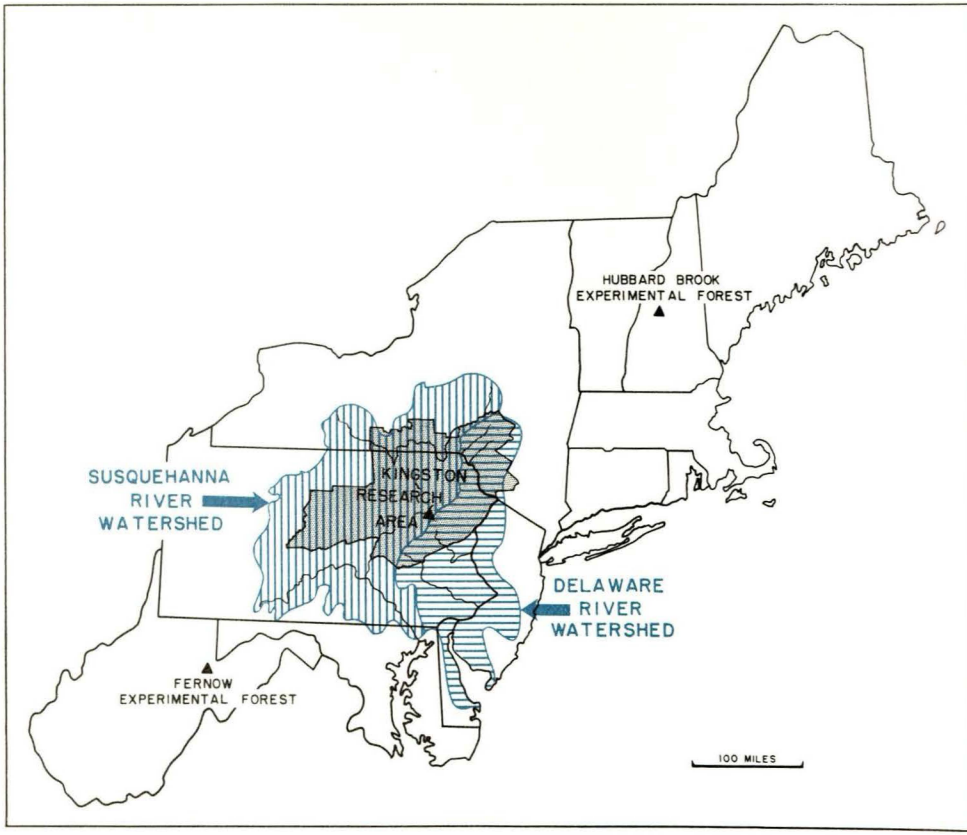


Figure 1.--The Kingston Research Center area lies within two major watershed areas, the Susquehanna and Delaware River basins. Other watershed management research is under way in New Hampshire and West Virginia.

primarily a study area for forest-management research; yet they also coincide roughly with headwater boundaries of two major watersheds.

In relation to northeastern watershed problems and research programs, the Kingston Center occupies a strategic position, for these reasons:

- It is on a line and about midway between centers of watershed research in the White Mountains of New Hampshire and the northward extension of the Appalachians in West Virginia, the Hubbard Brook and Fernow Experimental Forests, respectively (fig. 1).

- It occupies a major portion of the largest single watershed in the Northeast, the Susquehanna (whose area is slightly more than combined areas of Massachusetts, Vermont, and New Hampshire), and the upper third of the adjoining Delaware River watershed, source of metropolitan supplies. The combined watersheds form the largest single drainage area on the Atlantic Seaboard.

- It embraces at least four distinct topographic provinces in which forest watershed-management research has not been conducted: the Allegheny Plateau, the Catskills, the intervening river valleys devoted largely to agriculture, and the ridge and valley province marking the southern boundary.

- It is an area with manifold need for the two major objectives of watershed management: flood control and--the paradoxical objective--increasing public water supplies. On the basis of dollar damage, this is one of the highest flood-damage zones in the United States; it is also the source of water for the greatest concentration of people and industrial development in the United States.

The purpose of this analysis is threefold: (1) to present the physical features and resources of the Center's area as they bear on forest watershed management, (2) to present systematically the watershed problems and their sources through segregation and discussion of problem areas, and (3) to offer a program of watershed-management research. Presentation and sequence of this analysis will be in accordance with these objectives.

This by no means should be considered an exhaustive treatise based on years of on-the-ground experience; rather it is a brief bird's-eye view of what appears to be the watershed situation. No labored effort is required to find problems for research; with but forest-streamflow qualitative relations to go on, even the simplest types of quantitative data would be a contribution. Since the problems and the dearth of data are so manifest, the real immediate question is how to develop and organize a program of research.

The program suggested is for a short-term, 5-years--1957-1961--during which most of it can be accomplished. Largely it is exploratory, looking toward establishment of an adequate long-term program with cooperation of others in-

terested in this field of research. It is our hope that this analysis will stimulate both an interest in these problems and a cooperative effort towards their solution.

Current Research

FOREST WATERSHED research by the Northeastern Forest Experiment Station is being conducted at the Hubbard Brook Experimental Forest in the White Mountains of New Hampshire, the Delaware-Lehigh and Pocono Experimental Forests in Pennsylvania, and the Fernow Experimental Forest in West Virginia.

In New Hampshire, at the Hubbard Brook Experimental Forest, studies were recently started in an area of northern hardwoods, glacial soils, and mountainous terrain (14).[2] Here annual precipitation is about the same as in the Kingston area, around 40 inches; but about twice as much snow is received and temperature averages 10° F. lower. Elevation ranges from about 1,000 to 3,300 feet.

At the Fernow Experimental Forest in West Virginia, watershed studies are being conducted in Appalachian hardwood at elevations ranging from 1,750 to 3,554 feet (21). Forest types vary, with increasing elevation, from cove hardwoods to northern hardwoods and mixed oaks. Soils are residual and are similar to those in mountainous portions of the southern half of the Kingston area. Average annual temperature is about the same as Kingston area, around 45 to 50° F.; annual precipitation, between 45 and 55 inches, is somewhat greater.

Watershed research at the Delaware-Lehigh Experimental Forest of the Kingston Research Center was begun in 1948, in cooperation with the Pennsylvania Department of Forests and Waters and the U. S. Geological Survey. Its purpose is to determine the water economy of a scrub-oak watershed and the effect on that economy of converting the scrub oak cover to a commercial hardwood and conifer forest. Elevation of the 1,530-acre Dilldown watershed (within the Forest) ranges from 1,670 to 2,215 feet. Average annual temperature is

[2]Underlined numbers in parentheses refer to Literature Cited, page 31.

46° F.; average annual rainfall of about 50 inches exceeds the normal for the Kingston area because of the watershed's topographic position. Soils are residual podzols derived from sandstone and shale. Daily streamflow and climatic records date from October 1, 1948. Three progress reports have been issued: each gives a 2-year accounting of research accomplishments and daily records (10, 12, 13).

Data for the first 6 years are being analyzed to develop prediction equations for streamflow during the calibration or pre-treatment period. Deviations from predictions after treatment will be a measure of treatment effects on streamflow.

These analyses (results of which will be published) have indicated that 6 years' data are sufficient for development of prediction methods accurate enough to allow detection of small differences from treatment. Accordingly, plans were made for a 5-year planting program starting in the fall of 1955, as follows:

No treatment required	400 acres
Remove scrub oak:	
Plant	285 acres
Natural seeding	50 acres
Interplant in scrub oak	795 acres

Planting the watershed will bring the first part of this study--calibration and treatment--to a close. No effect on streamflow is envisaged until crown closure, which will take about 15 years. In the interim, attention can be directed to other watershed problems in the Kingston area--problems that will be pointed out in this analysis. New research will not be initiated, however, until results of the Dilldown and Pocono studies conducted during the calibration period have been reported.

Watershed research at the Kingston Center's Pocono Experimental Forest began in the fall of 1949 on a 560-acre watershed in northern hardwoods. Elevation of this watershed averages about 2,000 feet. Soils are glacial, gray-brown podzolic, and very stony. The objective of this study was to determine the effect of forest-management practices on water yield. Practices include protection, during which the growing stock will be built up, followed by management on a sustained-yield basis. Windthrow from hurricanes and

suppression of natural regeneration by deer have recently reduced the growing stock so that future treatment is now uncertain. Climatic and streamflow records will be analyzed within the next year to determine the degree of calibration achieved. A decision will then be made as to the ultimate research use of this area.

Watershed research at the Delaware-Lehigh and Pocono Experimental Forests has produced 8 years of daily climatic and streamflow records that should yield considerable information on the water economy of scrub oak and northern hardwood; supplementary data on interception, soils, and soil moistures have been taken; and considerable experience has been gained in watershed-research techniques. Now that these studies are, for the time being, becoming less active, knowledge and experience gained can be put to good use initiating research in other problem areas--areas of equal or perhaps greater importance in respect to watershed research needs.

In addition to watershed research conducted by the Kingston Research Center in cooperation with the Pennsylvania Department of Forests and Waters and the Geological Survey, both Cornell University and Pennsylvania State University have conducted studies in this field. At Cornell, studies at the Arnot Forest have been made as to the influence of hardpan soils, land use, and snow and frost on runoff (11). Recently a study of the characteristics and genesis of the Volusia and Mardin soil series has been reported.[3] At Pennsylvania State University, the School of Forestry has been active in conducting planting tests on strip-mined areas. The U.S. Geological Survey has been conducting a study since 1932 near Deposit, N. Y., on four watersheds to learn the effect of reforestation on water yield (1).

[3]Carlisle, Frank Jefferson, Jr. Characteristics of soils with fragipans in a podzol region. A thesis presented to the faculty of the Graduate School of Cornell University. 1954.

Watershed Relations and Resources

FOR WATERSHED purposes, three basic resources must be considered. The first, naturally, is water; the second, the forest cover that uses water and influences the disposition of the portion not used; the third, the soil that supports the forest and serves as both passageway and storage place for water.

WATER

Under the heading of water must come consideration of its primary source (precipitation), how much runs off (streamflow), and the difference (evapo-transpiration).

Precipitation

Annual precipitation in the Kingston area ranges from 32 to 46 inches (fig. 2). Distribution follows the normal pattern for the Northeast: greatest amounts are received in the eastern sections and mountain areas and the amounts drop markedly northwestward towards the Great Lakes. Average annual precipitation for Pennsylvania has been given as 42.14 inches (8), which is not much different from that received elsewhere in the Northeast. Within the Kingston Research Center's area, this amounts to around 30 million acre-feet, or about 15 acre-feet or 5 million gallons per capita. This

TABLE 1.--Average monthly rainfall at five stations, in inches (16)

Station	Total	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Elmira, Chemung County, New York	32.62	1.90	[1.70]	2.60	2.85	3.26	[3.74]	3.42	3.67	3.02	2.63	2.00	1.83
Jeffersonville, Sullivan County, New York	41.32	3.04	[2.74]	3.01	3.30	3.17	3.73	4.57	[4.77]	3.71	3.45	2.97	2.86
Wilkes-Barre, Luzerne County, Pennsylvania	37.74	[2.42]	2.53	2.88	3.01	3.05	4.03	[4.32]	3.86	3.56	3.06	2.28	2.74
Williamsport, Lycoming County, Pennsylvania	39.17	2.90	[2.46]	3.27	3.68	3.72	3.75	3.77	[3.92]	3.22	3.12	2.52	2.84
Lock Haven, Clinton County, Pennsylvania	40.11	3.07	2.43	3.38	3.58	3.94	[4.15]	4.02	[4.15]	3.29	3.09	[2.21]	2.80

Note: [ ] indicates highest; [ ] indicates lowest.

is more than can be used or retained on the watersheds, which accounts for the runoff.

Distribution throughout the year is quite even, as shown in table 1, which gives average monthly values for five widely separated stations based on 36- to 40-year records (16). June, July, and August are months of greatest

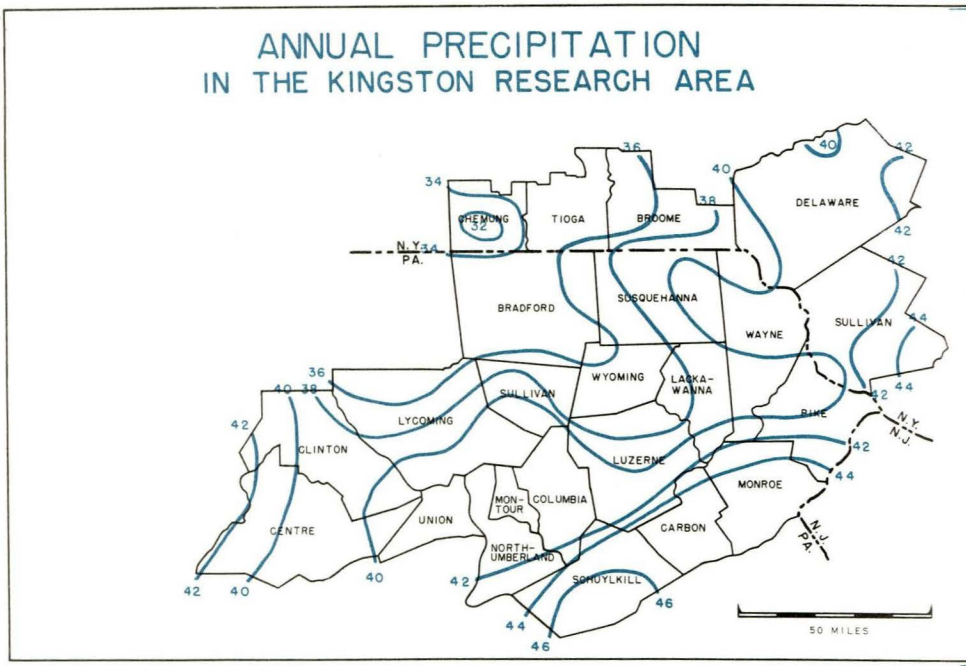


Figure 2.--Distribution of annual precipitation (in inches) in the Kingston Research Center area. Precipitation ranges from 32 to 46 inches.

precipitation; January and February are the driest months. However, these differences are minor compared with seasonal differences in demand by vegetation as affected by changes in temperature and day-length.

Perhaps 10 to 15 percent of the annual precipitation comes as snow, 40 to 60 inches a year. Only at high elevations in the New York State portion of the Kingston research area does a winter snowpack accumulate to add to spring runoff. In most of the region, winter thaws periodically melt

snow accumulation so that there is little opportunity for influencing water yield through forest cutting to increase snow accumulation by reducing interception.

Streamflow

Roughly about one-half of the precipitation runs off as streamflow; it is in this process that water is gathered together in usable quantities. For 14 stations in the Delaware River Basin, 17- to 19-year records showed an average precipitation of 43.85 inches and runoff of 23.55 inches or 53.7 percent. Comparable data for 27 stations in the Susquehanna Basin were 39.85 and 18.38 inches or 46.1 percent (8).

Streamflow distribution throughout the year (18) gives a much better picture of available water supplies than does rainfall distribution (table 2). During the summer months, June-September runoff has amounted to 18.6 and 15.0

TABLE 2.--Average monthly runoff from Delaware and Susquehanna watersheds, 1942-51

Month	Delaware River[1]		Susquehanna River[2]	
	Inches	Percent of total	Inches	Percent of total
January	2.32	9.1	2.16	10.3
February	1.86	7.3	1.70	8.1
March	4.48	17.6	3.98	18.9
April	3.56	13.9	3.17	15.1
May	3.18	12.5	2.93	14.0
June	1.67	6.6	1.45	6.9
July	1.35	5.3	.75	3.6
August	.87	3.4	.50	2.4
September	.81	3.3	.45	2.1
October	1.04	4.1	.75	3.6
November	2.08	8.2	1.48	7.0
December	2.22	8.7	1.68	8.0
	25.44	100.0	21.00	100.0

[1]From streamflow record at Port Jervis, N. Y. (18).
[2]From streamflow record at Sunbury, Penna. (18).

percent of the annual runoff for the Delaware and Susquehanna, respectively. Thus about 1/5th to 1/7th of the runoff was available in the 1/3rd of the year when demand was greatest.

An unhappy feature of streamflow distribution is the periodic occurrence of damaging high flows--floods--and low flows during times of drought.

Floods

At least nine major floods have occurred in the Kingston area. Severe floods of the Susquehanna in 1889 and 1936 were derived in large part from the unfortunate coincidence of heavy snow accumulation followed by rapid thaws and spring rains; the most recent flood resulted from heavy rainfalls accompanying two hurricanes. Though no attempt was made to collect information that would give the flood picture in detail, the following statements are suggestive:

- Annual damage due to floods in the eastern part of the Upper Susquehanna has been established at $149 per square mile of drainage area (20).
- Annual damage due to inundation on the Delaware River watershed is estimated to average $140 per square mile (17). Neither this estimate nor the one above includes damages from erosion and sedimentation.
- The floods of 1935-36 in Pennsylvania took 80 lives and caused damages of $54,082,500 in the Susquehanna watershed and $1,889,075 in the Delaware watershed (6).
- Within the Research Center's area major floods, whose magnitude closely approached the 1935-36 flood, occurred in 1865, 1889, 1894, 1901, 1903, and 1933 (6)

The most recent flood, on August 18-19, 1955, was due to heavy rainfalls associated with hurricanes Connie and Diane. Most of the damage in Pennsylvania, amounting statewide to over 70 million dollars, occurred in the Delaware Basin where discharges at many stations were the greatest on record (19). Eighty-eight lives were lost in Pennsylvania. Flood flows were particularly high in the Lackawaxen River basin, Brodhead Creek basin, and Lehigh River basin.

Droughts

Serious droughts have occurred in Pennsylvania in 1876, 1881, 1887, 1895, 1900, 1904, 1908, 1909, 1914, 1923,

1930 (7), and 1955. The 1930 drought was perhaps the worst, when mean precipitation for the State was 28.82 inches with a deficiency of 32 percent of normal rainfall; after this drought, safe yield of Pennsylvania streams was re-estimated to be about 0.05 csm or about 32,500 gallons per day per square mile of drainage area (7). This is about 1/30th of the mean daily yield (for the Susquehanna as measured at Sunbury, Pa.) of 1.45 csm or over 930,000 gallons per day (18).

Evapo-transpiration

Runoff or streamflow is the residual after evapo-transpiration demands have been met. It accounts for roughly half of the precipitation, or around 20 inches. Taking the previously cited figures for precipitation and runoff in the Delaware and Susquehanna basins, evapo-transpiration can be computed at 20.30 and 21.47 inches respectively.

Evapo-transpiration demand from month to month is illustrated by monthly streamflow values given in table 2. When evapo-transpiration demand is greatest, runoff is least; so that runoff during summer months may be roughly 1/4th to 1/2 that of winter months. Evapo-transpiration measurements from lysimeters at Coshocton, Ohio (about the same latitude as the southern portion of the research area), show average daily evapo-transpiration of about 0.06 inch during the winter and 0.15 to 0.20 inch during the summer months (3). Thus during summer months a soil-moisture deficit of about 1 inch can be built up in 5 to 7 days so that a 1-inch rainfall could contribute little to streamflow other than that portion that fell directly into the stream channel.

Differences in latitude are associated with climatic differences that affect evapo-transpiration. In Pennsylvania, for instance, annual evapo-transpiration has been estimated to be 18.5 inches at 42° latitude and 22.5 inches at 40°, a 4-inch difference (8). On this basis, the 2° difference between the northern and southern portions of the Kingston area might be associated with about a 3-inch difference in evapo-transpiration.

With annual evapo-transpiration of 20 inches--and if interception and evaporation from the soil can be estimated to consume 10 to 20 percent of an annual rainfall of about 42 inches--transpiration would then be in the neighborhood of 12 to 16 inches, most of which occurs during the growing season. It is a portion of this amount that can possibly be saved by manipulation of vegetation to increase water yields.

FORESTS

Since our basic premise is that forest treatment affects runoff and our obligation pertains only to forest watershed-management research, we are consequently interested in the extent of forest cover, the type of forest cover, and any qualitative influence that can be drawn as to forest-streamflow relationships.

Distribution of major forest types is shown in figure 3, and areas by softwood and hardwood types are given in table 3. Sixty-one percent of the Kingston Research Center area is in forest cover. Ninety percent of the forested

TABLE 3.--Forest types and areas

Item	Area	
	Acres	Percent of total area
Total area	10,247,000	100
Forest land	6,261,100	61
	Acres	Percent of total forest area
Softwood:		
White pine	266,100	4
Hemlock	169,900	3
Hard pine	102,200	2
Other	93,000	1
	631,200	10
Hardwood:		
Northern hardwood	2,492,000	40
Oak	2,814,900	45
Other	323,000	5
	5,629,900	90

area is in hardwoods and 10 percent in softwoods. The hardwood area is divided roughly between the northern hardwood and oak types.

Percent of area occupied by forest cover by counties is shown in figure 4 together with the major areas of state-

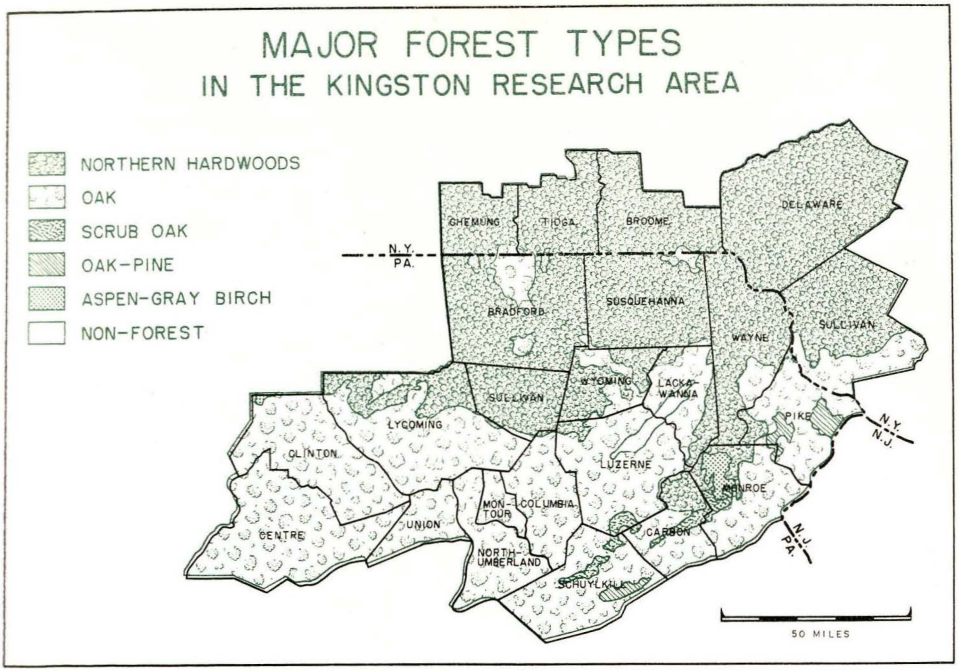


Figure 3.--Distribution of major forest types in the Kingston Research Center area. Hardwoods cover 90 percent of the forested area.

owned land[4] (9). The most extensive areas of forest land are in the Catskills and Poconos in the eastern section with 50 to 89 percent forest cover, and the Allegheny Plateau in the western portion where forest cover by counties ranges from 67 to 87 percent. In between are a group of four southern agricultural counties along the Susquehanna Valley where forest land occupies 28 to 53 percent of the area and a block of five northern dairy counties with forest cover of 40 to 50 percent.

About 1,200,000 acres or 18 percent of the forest land is state-owned. Largest state ownerships are in Clinton, Lycoming, and Centre Counties in Pennsylvania and Delaware County in New York.

[4]Stoltenberg, Carl H. The forest resources of the Kingston Research Area. Unpublished report, Northeastern Forest Experiment Station. 59 pp. 1954.

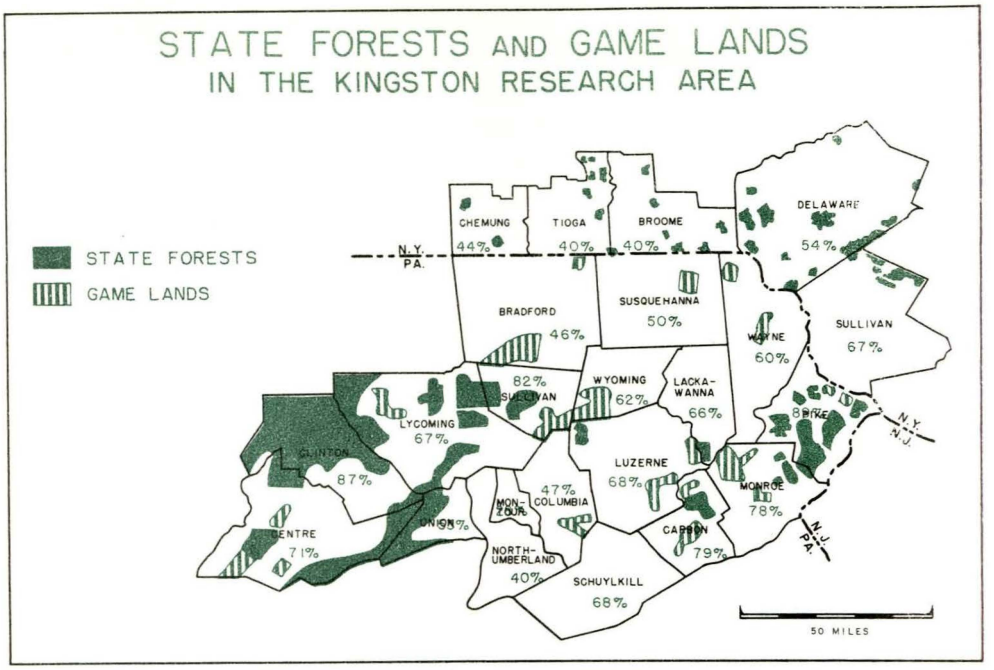


Figure 4.--Location of State Forests and Game Lands in the Kingston Research Center area. The percentage figures show how much of each county is covered by forest.

To assess the watershed condition of the forest cover the percent of commercial forest area occupied by sawtimber, pole-timber, and seedling-sapling stand-size classes was calculated from Forest Survey statistics for three regions: Delaware and Sullivan Counties in the Pocono-Catskill region of New York, Lycoming and Clinton Counties in the Allegheny Plateau section of Pennsylvania, and Carbon and Centre Counties in the Ridge and Valley Region. Percentages were as follows:

	Delaware-Sullivan	Lycoming-Clinton	Centre-Carbon
Sawtimber stands	39	25	13
Poletimber stands	47	65	49
Seedling-sapling stands	14	9	35

Since size-class is a rough indicator of hydrologic conditions, the above tabulation indicates that most of the forest land is not exerting its potential protective influence, a possibility that ties into local observations, and that

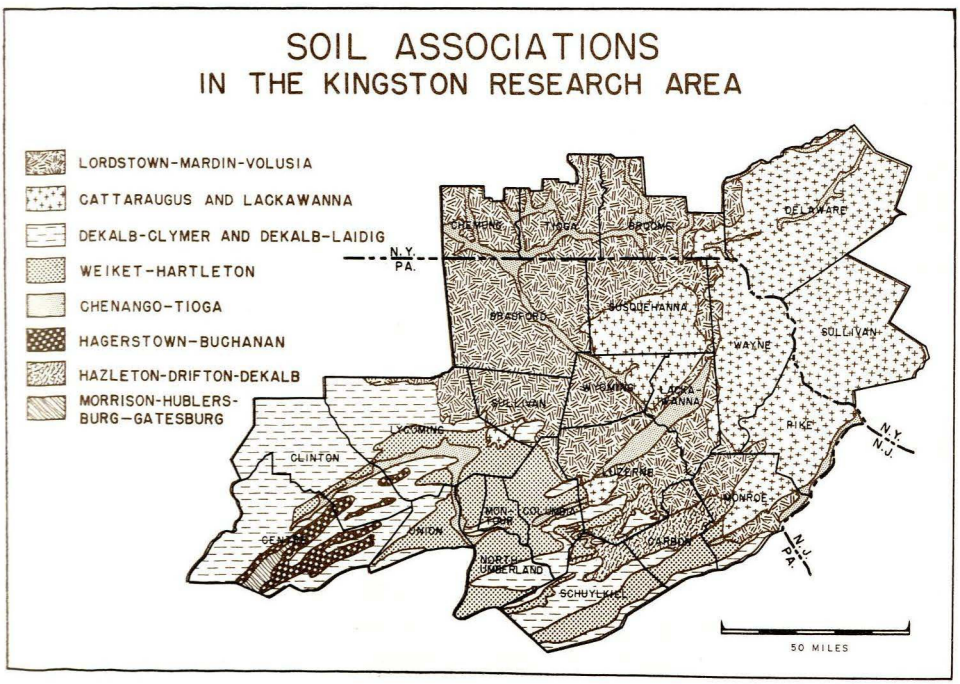
use of water may increase with continued forest growth. Both points bear investigation. The tabulation also indicates that conditions favoring flood control are more common in the Pocono-Catskill Region than in more southerly regions; poorest conditions are in the Ridge and Valley Region.

SOILS

Forest and water relationships are rooted literally, and figuratively, in the soil. Soils are residual in most of the western part of the area; the remainder has been variously affected by glaciation. The terminal moraine of the Wisconsin glacier cuts through the northeastern part of Lycoming County, including Sullivan and most of Luzerne and Monroe Counties. The soils above this line were distinctly affected by glaciation.

Older glaciation has affected the rest of the eastern part of the area and extends into Union County with a long finger cutting through Lycoming and Clinton Counties. The marks of this older glaciation are much less distinct.

Figure 5.--General distribution of the soil associations in the Kingston Research Center area *(15)*.



In most of the acid soils modified by the Wisconsin glacier, a tightly packed and slowly permeable subsoil is found. This horizon is called a fragipan (2); it is very hard when dry but is fairly friable when wet. It is so tightly packed and has so little pore space that few roots will penetrate it. Though it retards downward movement of water, nevertheless groundwater is recharged by slow percolation through it.

Figure 5 shows a generalization of the numerous soil associations in the area. Information on soil associations was obtained from published reports (2, 4) and from consultation with F. G. Loughry, state soil scientist, Soil Conservation Service, Harrisburg, Pa. The authors then grouped many associations having similar characteristics.

Lordstown-Mardin-Volusia Association

Soils from glaciated till, gray shale, and sandstone. Moderate podsols. All have fragipans except Lordstown. Lordstown on the higher slopes is shallow, about 2 feet deep to compact till and 3 feet to bedrock, and is well drained. Mardin, on lower slopes, is about 18 inches deep to the fragipan and moderately well drained. Volusia is on the lower slopes and flats; it is somewhat poorly drained and shallow with a depth of 6 to 12 inches to fragipan. All soils are generally stony and flaggy. The Stroudsburg Valley, included in this association, is at a lower elevation and has local areas of limestone soils.

Cattaraugus & Lackawanna Associations

Soils derived from glacial tills and generally somewhat deeper than the Lordstown-Mardin-Volusia association. The Cattaraugus association was formed from red and gray shale and sandstone, while the parent material of the latter was red shale and sandstone. Bedrock ranges in depth from 30 to 48 inches. All series are moderate podsols; all have fragipans except Oguaga, which is a component of both associations. Cattaraugus and Lackawanna are the deep well-drained members of their respective associations. Culvers and Wellsboro are also deep but only moderately well drained, while Morris is the somewhat poorly drained component of both associations. Oguaga is shallow and well drained. All soils are generally stony.

Dekalb-Clymer & Dekalb-Laidig Associations

These associations are found on the mountainous areas of the southern and western part of the Research Centers' area. The former association covers nearly all the non-glaciated Allegheny Plateau; the latter is found on sandstone ridges east of the plateau. The western zone of Dekalb-Laidig is on a non-glaciated area, but the eastern section, which includes the southern anthracite coal fields, was influenced by the older glaciation. The soils are mostly stony and variable in depth. Natural drainage is generally good. Soils on slopes are frequently shallow, 6 to 12 inches deep to disintegrated bedrock.

Weikert-Hartleton Association

Soils formed in broad shale and sandstone valleys between the mountain ridges. These are the most extensive agricultural soils of the area. They are mostly shallow or only moderately deep and relatively free of stones. Drainage is generally good. A few areas of deep limestone soils are included in this association.

Chenango-Tioga Association

These are found in valleys of major streams. Soils are deep and mostly well drained, although the flood plains include considerable poorly drained land.

Hagerstown-Buchanan Association

These are valley soils formed from limestone surrounded by shale. They are deep and mostly well drained. The shale areas along the valley sides are somewhat poorly drained. Fertility and moisture capacity is high.

Hazleton-Drifton-Dekalb Association

These soils are found on Broad Mountain and part of the Pocono Plateau. Soils on top of the Plateau are moderately deep and well drained. The parent material was mostly sandstone with some shale, mixed by early glaciation. Nearly

all the area has remained in forest. The Dilldown Watershed lies in this soil association.

Morrison-Hublersburg-
Gatesburg Associations

This soil association is found in the Barrens of Nittany Valley. It is an area of broad low ridges a little higher than the adjacent limestone lands. Parent material was soft sandstone that contained varying amounts of lime, but is now leached to great depths. Soils are mostly deep sands and sandy loams, excessively drained with low moisture capacity.

The most important hydrological feature of the above described soil associations is their general shallowness, indicating low storage capacity. Due to prevailing immature forest stands, humus depths also tend to be shallow. In light of the limited soil-water storage, development of maximum humus depths should be an important flood-control objective.

Largely because of the preponderance of forest cover, erosion is not a serious problem. However, streambank erosion is serious in some areas. Also, moderate erosion occurs on some of the steep pasture lands in the northern section. Some gullying is association with woods roads (4); early photographs of heavily logged-over areas show considerable erosion. An interesting project would be an examination of these areas to determine their present condition in respect to erosion and the depth of humus built up since logging.

Frozen soil, a factor of greater hydrologic importance, has received some study in the Poconos and Catskills.[5] During two winters, concrete frost observed in the Catskills averaged 4.8 inches deep in open land and 3.2 inches in forest land. Comparable figures for the Poconos were 4.2 and 2.1 inches. Concrete frost occurred in 43 to 70 percent of frost observations made in open land in the Catskills and 74 to 82 percent in similar areas in the Poconos. In forested areas of various types and conditions, frost was noted in 24 to 64 percent of the observations made in the Catskills and 15 to 54 percent of those in the

[5]Pierce, Robert S., Lull, H.W., and Storey, H.C. Influence of land use and forest condition on soil freezing and snow depth. Report in preparation for publication. Northeastern Forest Experiment Station. 1956.

Poconos. Concrete frost was seldom found in well-protected forest areas that had a dense cover and a normal accumulation of humus. Where it occurs, concrete frost reduces infiltration and increases surface runoff.

SUMMARY

From this brief review certain facts and relationships that pertain to watershed problems and management stand out:

- Average annual precipitation of 42 inches is distributed uniformly throughout the year, providing excess water supplies during the winter dormant season and insufficient amounts during growing season.

- For most of the region snow is not an important component of precipitation and therefore is not susceptible to management. Winter snowpacks do accumulate at higher elevations in the northern portion.

- About one-half of the area's precipitation runs off as streamflow; 1/5th to 1/7th of the annual discharge occurs during the four summer months.

- Floods and droughts have occurred frequently and have caused tremendous damage: average annual flood damages amount to about $140 per square mile.

- About one-half of the precipitation is lost through evapo-transpiration, and perhaps one-third by transpiration alone.

- Forest cover is immature and probably does not provide potential flood protection or use maximum amounts of water.

- Soils tend to be shallow with low storage capacities; this accentuates the importance of humus development to increase soil storage.

- Concrete frost in the soil is extensive and may be an important factor influencing winter and spring runoff.

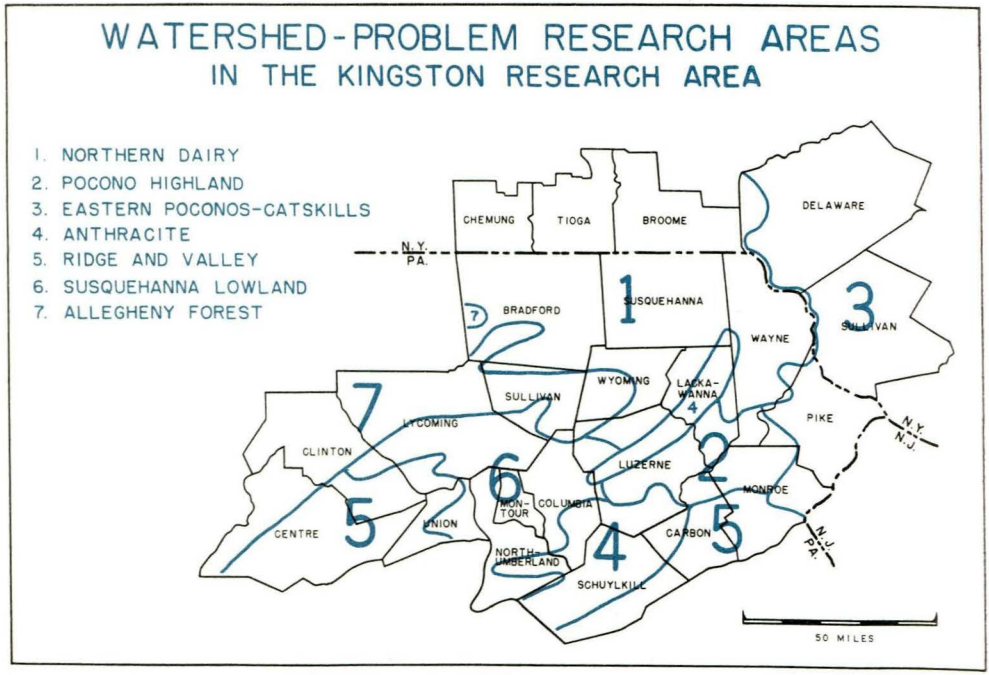
Application of these conclusions to specific problems will be undertaken in the next section.

Problem Regions

THE KINGSTON research area has been divided into seven regions (fig. 6), based largely on differences in physiography and related land use. These represent a synthesis of geographic divisions (5) and problem areas devised by the Soil Conservation Service (4).

The largest region is the Northern Dairy Region, which takes in about six counties and comprises 30 percent of the research area. Immediately to the east is the Eastern Pocono-Catskill Region, which includes 20 percent of the research area. On the western side is the Allegheny Forest Region, occupying 14 percent of the area, its boundary marking the edge of the Allegheny Plateau.

Figure 6.--For purposes of planning research programs, the Kingston Research Center area has been divided into seven problem regions.



These three larger regions surround four smaller regions. One, the Anthracite Region, 8 percent of the research area, is divided into two parts marking the location of the northern and southern coal fields. The Pocono Highland, 5 percent, denotes an area largely in scrub oak. The Ridge and Valley Region crosses the southern boundary at two points and occupies 12 percent of the area. Finally, the Susquehanna Lowland Region, predominantly agricultural, is located in the south-central part and takes up 11 percent of the research area. Characteristics and problems of each region will be discussed in following sections.

NORTHERN DAIRY REGION

The Northern Dairy Region is predominantly an upland plateau with extensive areas of even hilltops ranging in elevation from 1,600 to 2,000 feet. About 70 percent of the area is in farms of about 150 acres, of which one-third is woodland; about one-half of the farm woodland is grazed. Most of the open land is pasture and much of it occupies steep slopes. Extensive areas have hardpan or tight silty clay subsoil (the Volusia and associated series), which limits depth of soil-water storage. Hardwood forests may be expected to increase in extent as steep slopes are found unsuitable to agriculture. In Broome County there are over 100,000 acres of cleared idle land, almost one-fourth of the county's area.

Watershed-Research Problems

Problems revolve around three factors: hardpan soils with low storage; hydrology of steep idle land; and the effect of woodland grazing.

1. Hardpan soils. The Volusia-Mardin and associated soils represent the most extensive area of shallow, poorly drained, hardpan soils in the humid East. With their low moisture-storage opportunity, these soils are a primary source of flood runoff (11). Investigation might include the following:

   (a) Detailed examination of the Volusia problem to determine soil-moisture and ground-water-level regimens, and depth of rooting and penetration--if any--of hardpan; exploration of possibilities of mechanical penetration of hardpan; comparison of

published streamflow and well records from hardpan and well-drained soil areas.

(b) Gaging small forested watersheds to determine comparative effects of Volusia soils on runoff, as compared to Lordstown or better drained soils.

2. Steep, idle land. A striking feature of this region is the steeply sloping pastures that are reverting to woodland. In connection with the frequent flooding of the Upper Susquehanna, runoff characteristics of these lands should be compared with those of forest plantations and brush lands grown up from pasture.

3. Woodland grazing. This is a perennial problem that may be eliminated in time if farmers find that it doesn't pay. A neglected aspect of this problem is to determine how long it takes for woodland soils and cover to recover from grazing. In pursuing such an investigation, opportunity should be taken to determine the effect of grazing from its beginning.

EASTERN POCONO-CATSKILL REGION

This is one of the three extensive forest regions, the others being the Allegheny Forest and the Pocono Highland regions. The Eastern Pocono-Catskills is a hilly upland with abundant streams, lakes, and swamps. Soils are variable in depth and invariably stony. The bulk of the land is privately owned, state ownership accounting for no more than 10 percent of the area. As has been noted, forest cover of this region is in better condition than cover in the Allegheny Forest and Ridge and Valley Regions.

Watershed-Research Problems

Possible problems for study come under two headings, flood control and water yield.

1. Flood control. Recent floods from forested watersheds have re-emphasized the need for flood control. Following the floods came an immediate question: What role did the forest cover play in flood control? No clear-cut answer could be given. A concomitant question is: What is the potential for flood control?

2. Water yield. Metropolitan areas are now drawing on the upper Delaware for water supplies or are planning to do so. Inevitably this will raise problems of watershed management: methods of increasing water yield, possibilities of conducting timber operations without polluting supplies, and methods of watershed protection. Studies should be started in the near future to provide timely answers and demonstration areas.

POCONO HIGHLAND

This is largely the scrub-oak region in which current watershed-research studies are being conducted at the Dilldown watershed. No additional work is contemplated.

ANTHRACITE REGION

This is an area characterized by spoil banks, strip-mining, frequent forest fires, flash floods, and landslides. Though relatively small, it probably is in need of more watershed rehabilitation than any other comparable area in the East.

Watershed-Research Problems

With heavy forest cutting, frequent burning, and the profusion of industrial waste, watershed research has many opportunities for rehabilitation studies. Suggested specific studies:

1. Spoil banks. Investigate the hydrology of spoil banks: determine infiltration, runoff, and moisture available for plant growth.

2. Strip-mining. On a survey basis, record the effect of strip-mining on streamflow. This is a current question and one that cannot well be answered by designed studies but can be studied by observational surveys.

3. Water yield. Several water companies have indicated an interest in cooperating on studies of the effect of forest type, condition, and treatment on water yields.

4. Fire. Compare hydrology of frequently burned and protected areas in regard to infiltration, soil-moisture-

storage capacity and opportunity, and surface runoff and erosion.

RIDGE & VALLEY REGION

This is a region of parallel steep sandstone ridges and intervening broad valleys. The valleys are devoted largely to agriculture; about one-half of the region is in farms. The southwestern portion includes the fertile Nittany Valley with limestone soils. It also includes a 30,000-acre area of sandy soils with scrub oak cover.

Watershed-Research Problems

Watershed-research interests lie in the ridge portions of the region. From observation and from the previous comparison of forested conditions these ridges appear to be poorer forest sites than either the Allegheny or Pocono-Catskill extensive forests. Soils are shallow, forest growth appears to be poor, and humus accumulation is shallow. Particularly pertinent would be determination of the soil-moisture-storage characteristics and the opportunity, if any, for increasing storage through addition of humus. Shale hills, at the foot of these ridges, offer a similar and interesting field of study. They are characterized by erosive soil and a changing forest cover as hardwoods invade old-field Virginia pine stands.

SUSQUEHANNA LOWLAND

This is a general farming region. About 60 percent of the area is in farms averaging 100 acres in size with 1/4th to 1/3rd in woodland. Less than 10 percent of the farm woodland is grazed. Idle or abandoned land is uncommon.[6] Forest-watershed-management problems are not serious.

ALLEGHENY FOREST

This region covers the high eastern part of the Allegheny Plateau. Its elevation, reaching 2,400 feet, is higher

[6]See footnote 4.

than most of the Plateau farther west. The West Branch of the Susquehanna has cut a narrow valley, to depths of 1,000 feet, through the Plateau and the courses of its principal tributaries are marked by sharp notches in its surface. Northwest of Lock Haven, stream dissection has produced some of the most rugged country in Pennsylvania. North of Williamsport the Plateau surface is well-developed with great massive interstream areas.

Forty to fifty years ago this was an active lumbering area. Cutting was heavy, and regrowth apparently has not been rapid. Soils are regarded as infertile. Sixty-four percent of this region is in State ownership as either State Forests or Game Lands.

Watershed-Research Problems

Flood control is the dominant problem in this region. Topography, drainage pattern, and forest conditions are such as to encourage high flows from heavy precipitation. There is a strong possibility that past heavy forest cutting created conditions that facilitated runoff. From observa-

TABLE 4.--Watershed problems, by regions

Region	Area			Research problems
	Total area		Percent forested	
	Acres	Percent	Percent	
Northern Dairy	3,088,548	30	52	1. Hardpan soils 2. Steep idle land 3. Woodland grazing
Eastern Pocono-Catskills	2,066,308	20	67	1. Flood control 2. Water yield
Pocono Highland	543,911	5	67	1. Scrub oak conversion
Anthracite	836,360	8	65	1. Spoil banks 2. Strip-mining 3. Water yield 4. Fire
Ridge and Valley	1,232,714	12	72	1. Soil-moisture storage
Susquehanna Lowland	1,087,522	11	50	
Allegheny Forest	1,391,235	14	77	1. Flood control

tion, the present condition of the forest land does not inspire confidence in its flood-protecting capacity.

Accentuating this problem is the fact that much of this regrowth is approaching commercial size and will be subject again to logging. Before extensive re-cutting there is a real need for information on streamflow under present conditions compared with flow from cut-over areas and, if possible, with flow from non-typical watersheds with essentially undisturbed cover. Extensive State holdings may offer a location for a program of gaging and treating a number of small forested watersheds.

SUMMARY

Watershed-research problems by areas are summarized in table 4. In all, 12 problems are listed for the seven regions. Of these, the problems in the two extensive forest areas, the Eastern Pocono-Catskill and the Allegheny Regions, and in the Northern Dairy and Anthracite Regions, deserve first attention.

Research Program

TO EMBARK on a watershed-research program designed to meet the research needs described requires: (1) more specific information on individual research problems and (2) participation of a number of interested agencies and institutions. Time has not permitted meeting either requirement. Therefore, a period is needed during which cooperative relations can be established and a few studies can be begun to answer, or at least better define, some of the more pressing problems.

To that end, a 5-point research program is proposed for the next 5 years. It will include research in three of the problem regions (the Northern Dairy, Anthracite, and Allegheny Regions) and two general surveys, one to establish a basis for watershed classification, and the other an economic appraisal of water production from forest lands.

The degree to which this program can be accomplished will depend in large part on the degree of participation obtained; it will also foretell possibilities of achieving a

larger program. In the following sections a brief discussion of each of the five projects will be given, together with a list of possible cooperators. Only the probable direction that individual studies will take can be indicated here. Before initiation of any one study a detailed work plan will be prepared according to a standard practice, giving objective, scope, design, and methods.

1. NORTHERN DAIRY REGION

Three studies are suggested for this region. Two are exploratory in nature, to define the hydrology of steep idle land and of forest-occupied hardpan soils: the third is to determine duration of woodland grazing effects on hydrological properties of the soil and the effect of treatment on duration.

Hydrology Of Steep Idle Land

The objective will be to determine the characteristics of these areas that affect water disposal as compared with disposal of waters from forest lands. This will involve measurements of infiltration, percolation, soil-moisture storage, and soil density; and periodic measurements of soil-moisture content to establish some conception of moisture utilization and storage opportunity. Frost type and penetration will be compared in pasture and woodland. The study will be conducted by periodic visits to selected areas--perhaps on the order of 6 to 10 visits during the year to 10 to 15 areas--to collect samples and take measurements. Visits should be spaced to coincide with periods of soil wetness, dryness, and freezing.

Hydrology Of Forest-Occupied Hardpan Soils

Pertinent study objectives will include soil-moisture measurements to determine depth of moisture removal, measurements to determine ground-water levels in or below hardpan, excavations to determine depths to and depths of hardpan, and measurements of infiltration, percolation, and bulk density to determine physical characteristics of the hardpan and overlying soil.

Duration Of Woodland Grazing Effects

Infiltration, percolation, and soil density will be measured annually on a number of fenced sample plots in grazed woodland to determine duration of grazing effects. The study can be designed to permit also determination of the efficacy of different methods of rehabilitation. Frost occurrence should also be investigated.

Participants

Before beginning this study advice and cooperation should be sought from: Department of Agronomy, Cornell University, Ithaca, N. Y.; Soil Conservation Service, Cornell University, Ithaca, N. Y.; Watershed Hydrology Section, Agricultural Research Service, Cohocton, N. Y.; and State University of New York, College of Forestry, Syracuse, N. Y.

2. ANTHRACITE REGION

Three studies are suggested in the Anthracite Region: a survey of the effects of strip-mining on streamflow; a study of the hydrology of spoil banks; and a determination of the effects of strip-mining and spoil-bank planting on infiltration, surface runoff, and erosion.

Effects Of Strip-Mining

The effect of strip-mining on streamflow, though obvious, has never been given systematic study. While denudation of cover by strip-mining can serve to increase surface runoff and erosion and thereby raise streamflow peaks and lower quality, quantitative effects can vary widely depending on such variable factors as size of area denuded, its position in relation to stream channels, slope, soil wetness, and the like. Because of this inherent variation, rigorously designed studies are not feasible; a simple and practical approach may be to determine effects at a number of locations by measurements of peak flows, periodic samplings, water-quality measurements, and observation of channel conditions. These, together with a series of photographs, should provide at least documentary information of strip-mining effects.

Hydrology Of Spoil Banks

The objective of this study will be to determine the hydrological characteristics of spoil banks, particularly their contributions to surface runoff and erosion. This will involve, as in other studies, periodic measurement of infiltration, percolation, soil density, and soil-moisture content on representative areas.

Hydrologic Effects Of Planting Strip-Mines & Spoil Banks

This study will consist of a survey of experimental plantings to determine their effect on infiltration, surface runoff, erosion, and creation--through evapo-transpiration--of soil moisture-storage opportunity. Particular attention will be paid to depth of soil-moisture drying under different types of planting, and build-up of humus.

Participants

Advice and cooperation of the following will be solicited: Large landowners including coal companies; Pennsylvania Department of Forests and Waters, Harrisburg, Pa.; and Pennsylvania State University School of Forestry, University Park, Pa.

3. ALLEGHENY REGION

In this region a watershed study is contemplated involving stream-gaging and treatment of three to five forested watersheds of sufficient size, perhaps 50 to 100 acres, to have perennial flow. As in the Dilldown study, gaging would be continued for a period of perhaps 5 years to determine streamflow characteristics, after which one watershed would be selected as a control and the others would be subjected to different degrees of cutting. The effect on water yield, distribution, and quality would then be determined. A cooperative arrangement similar to that at the Dilldown watershed is envisaged.

Participants

Pennsylvania Department of Forests and Waters, Harrisburg, Pa.; and Geological Survey, Department of Interior, Harrisburg, Pa.

4. WATERSHED CLASSIFICATION

The objective of this study is to obtain sufficient information to permit development of a forest-watershed classification system for three regions: the Pocono-Catskills, Allegheny, and Ridge and Valley. Largely, this would be an integration job, bringing data on forest cover, soils, and streamflow together plus results from observation and field sampling into a usable system of forest classification from the watershed condition standpoint. First of all it may involve establishment of base conditions by visiting and studying areas that have been under long-term protection. It will also require development of a survey procedure calling for periodic checking of watershed conditions in the various regions through measurement and observation of infiltration, percolation, and soil-moisture depletion.

Participants

Pennsylvania Department of Forests and Waters, Harrisburg, Pa.; and Pennsylvania State University School of Forestry, University Park, Pa.

5. WATER ECONOMICS

Underlying the entire concept of forest influences and forest-watershed management is the general assumption that forest cover, when protected, has a beneficial effect on streamflow, tending to smooth out the peaks, maintain summer flow, and yield water of good quality. More recently there has developed from research other possibilities such as increasing water yields when necessary by forest cutting, and practical systems for minimizing water-quality damage from logging.

An important question is: How much is this worth? What are the economic values of these beneficial effects? The answer would give us at least some idea about how much protection and treatment forested watersheds can be given, based on their water-yielding value.

As an exploratory study in this research area it is proposed that case histories of at least one watershed in the three major forest regions be prepared in which water yield from forested lands can be estimated, water uses and their value compiled, the protection and other influences assessed, and some estimate of water value developed.

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